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IDENTIFYING DIFFERENT DETERMINANTS OF ASSET LIFE

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Engineering asset management (EAM) involves the life cycle management of engineered physical assets. Within EAM, accurate asset life prediction is an essential scientific research problem. Asset life is defined and evaluated based on four aspects: physical, social and environmental, economic, and technological. Each aspect is represented by a set of determinants. A number of models have been developed to predict the life of an asset; however, most of these models are focused on one aspect. A model jointly considering different aspects of asset life is still highly desired because asset life is a complex function of multiple aspects and determinants. The identification of these determinants is an essential task in asset life prediction. However, a comprehensive literature review has not revealed these sets of determinants and their relationships. The synergies or relationships among these determinants are complex. In order to identify these relationships, existing models are reviewed and analysed to extract the determinants as a foundation for further research. In this paper, these determinants are extracted and identified by surveying and analysing existing models in each aspect of asset life. Furthermore, to model interactions and interrelationships among the determinants, the system dynamics approach is proposed to establish a preliminary influence diagram, which is the first attempt to model the relationships of determinants of each aspect.

Key Words: Asset life, Physical life, Technological life, Economic life, Social and environmental life, Complex systems, System dynamics

1 INTRODUCTION

Engineering asset management (EAM) is concerned with the life cycle management of engineered physical assets in order to achieve the business objectives of an organisation that owns or manages a pool of assets. EAM embodies the whole life cycle of an asset covering acquisition, design, installation, maintenance, and operation, and disposal stages. Plant operation and whole life cycle management of an asset need to have information for long term prediction. Asset owners and legislation authorities both require long term asset planning and budgeting; without longer term prediction in the health degradation process, it is impossible to meet this requirement. Therefore, asset life prediction is an indispensable scientific research problem for EAM.

Current research in asset life prediction indicates that there are four aspects of an asset's life expectancy [1]: physical, social and environmental, technological, and economic. The role of asset life prediction has assumed new dimensions in recent years primarily as a result of increased global competition and complexity of large systems. Defence, telecommunications, aviation, space, nuclear power plant, commercial aircraft, hospital equipment and skyscrapers are examples of such systems. Long term and accurate prediction of the life of an asset is not reliable, as traditional methods focus on one aspect to predict the life of an asset. However, asset life is a complex function of multiple aspects, with each aspect being a complex function of multiple determinants. Therefore, several aspects of asset life, as well as the determinants of each aspect must be considered in order to have holistic and accurate view of asset life. A comprehensive review has not revealed the different determinants of asset life, neither interrelationships and synergies among the determinants [2-10].

The purpose of this paper is to identify the determinants of each aspect of asset life, which are extracted and identified from existing models in literature. Moreover, in order to model interrelationships among the determinants, a system dynamics model is applied and a preliminary influence diagram is established. The remainder of this paper is structured as follows: Section 2 presents the definition of asset life and discusses the different aspects of asset life and their determinants. In Section 3 system

dynamics and a preliminary influence diagram are described. In Section 4 concluding remarks and future research directions are discussed.

2 DEFINITION OF ASSET LIFE

There are four possible aspects of asset life that need to be considered in order to evaluate the life span of an asset [1]. The four aspects of asset life are defined as: physical, social and environmental, economic, and technological. Physical life is the period over which an asset is expected to last physically, i.e. when replacement or major rehabilitation is physically required [1, 11]. The social and environmental aspects of asset life is defined as the period until human desire or legal requirement stipulates replacement [1]. Economic life of an asset is the period until economic obsolescence requires replacement with a lower cost alternative [1, 11]. Technological life of an asset is defined as the period until technological change dictates replacement due to the development of a technologically superior alternative [1, 11].

Figure 1 illustrates these aspects as well as the determinants of each aspect. This diagram depicts both aspects and determinants in order to have a holistic view of asset life. A number of models have been developed to predict the life of an asset; however, most of these models are focused on one aspect. It is necessary for long term and accurate prediction to develop models that identify and consider those aspects and determinants jointly.

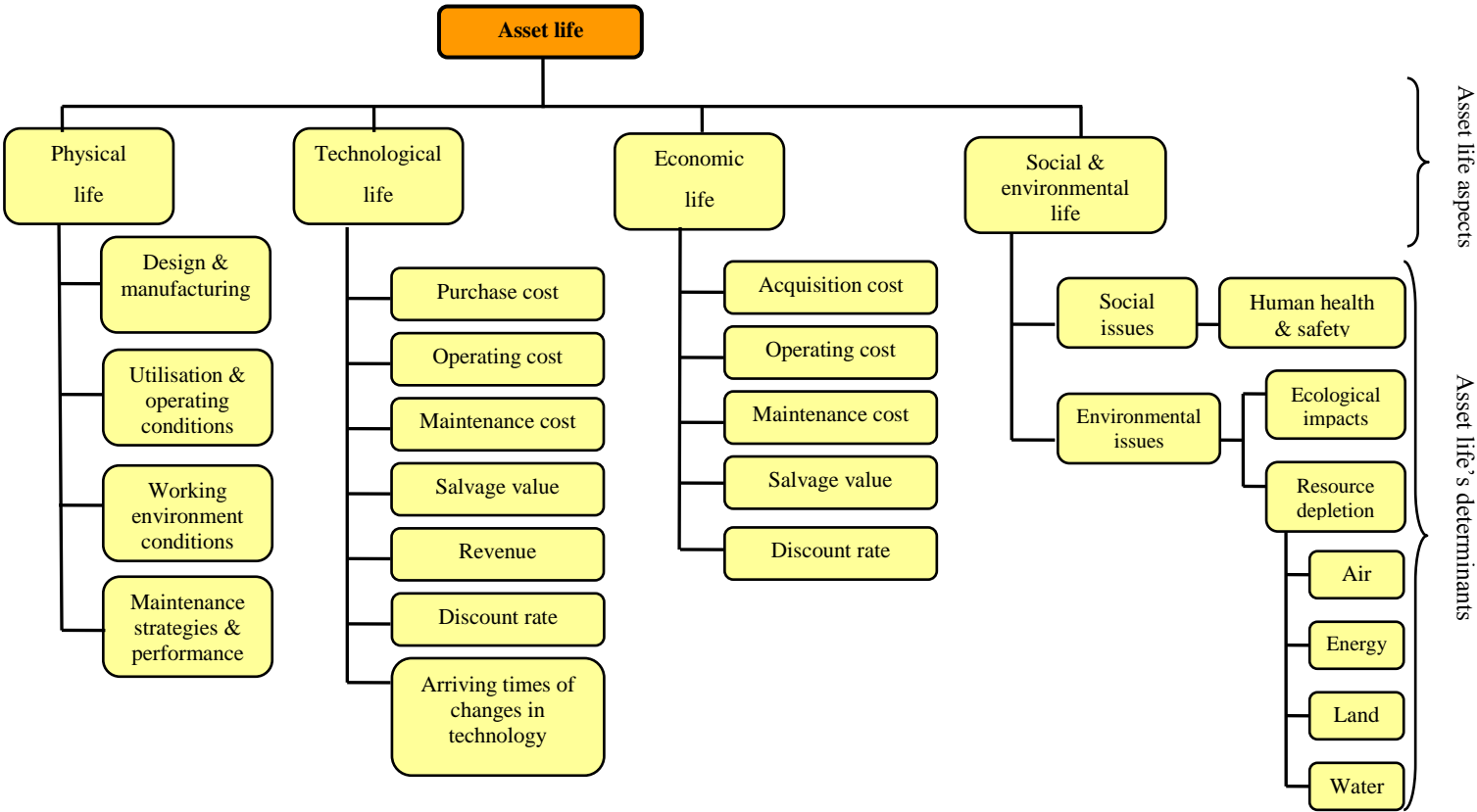


Figure 1. Aspects and determinants of asset life

The physical aspect of asset life is generally modelled through likelihood of failure mode [3]. The social and environmental aspects of asset life are described as life cycle assessment (a process for assessing and evaluating the environmental, occupational health and resource consequences of a product through all phases of its life) [4, 12]. In general, the environmental and social aspects of asset life are modelled by using environmental degradation, resource depletion and social issues due to product, process, and activities of industries. The technological aspect of asset life is usually modelled by improved efficiency, such as higher production rates, reduced operating and maintenance costs, and/or higher salvage values for further challengers. The economic aspect of asset life is usually modelled through increasing operating and maintenance costs and/or decreasing salvage values of the asset currently owned (defender). Each aspect of asset life is discussed as follows.

2.1 Physical life

The physical life is the period over which the asset may be expected to last physically, to when replacement or major rehabilitation is physically required. In other words, a piece of equipment starts to operate from its brand-new condition to a status in which it can no longer be used in the normal operating state and must be retired [1, 11].

The physical aspect of asset life would be represented as design life and actual life. Design (or nominal) life of an asset is the period during which the item is expected by its designer to function within its specified parameters. In other words, it is the life expectancy of an asset under the nominal operating conditions. Design life of an asset is normally specified during design stage with certain assumptions of nominal operating conditions. This number is defined under assumptions of nominal operating conditions. Actual (or operating) life of an asset is defined as the period during which the item functions under the real operating and environmental conditions. In other words, it is the life expectancy of an asset under the operating and environmental conditions.

Based on reviewing existing models of the physical aspect of asset life, the physical life of an asset can be evaluated by four determinants: design and manufacturing factors, utilisation and operational conditions, working environment conditions, and maintenance strategies and performance as shown in Figure 1.

Design and manufacturing factors, which can be influenced by the designer and manufacturer, affect on the physical aspect of asset life. These factors related to the type of design or material and also to the production processes of a product (asset). Quality of design will be affected by the functional performance of an asset. Design and manufacturing factors can be divided into poor, normal or good design and manufacturing.

The physical aspect of asset life is conditioned by different kinds of operational and environmental mechanisms, which affect it along the chronological time elapsed since the moment it is installed. Therefore, an asset under normal working conditions (operational and environmental), coincides with the chronological time elapsed. However, if the asset is exposed to adverse working conditions, its age evolves faster than chronological time. The different working environment conditions can affect the physical life of assets. The working environment conditions represent the environmental factors under which the component is working, such as temperature, pressure, humidity, doses of radiation, and so on.

The effect of the maintenance and surveillance actions on the state of physical life is based on two extreme conditions [13]. One possibility supposes that the state of the asset after maintenance is “as good as new”, which means its age is restored to zero after maintenance. The second possibility assumes that the maintenance leaves the asset in an “as bad as old” condition, in which the age of the asset after the maintenance is the same as its age immediately before it.

2.2 Technological life

The technological life of an asset is defined as the period until technological change dictates replacement due to the development of a technologically superior alternative. For example, a new technology is developed for a type of equipment and manufacturers no longer produce spare parts [1, 9, 11]. Therefore, firms can not obtain the necessary parts or components become too expensive for maintenance due to their scarcity in the dynamic market. In addition, technological change can affect the productivity and competitiveness of firms. In general, technological change is quantified by improved efficiency; for example, higher production rates, reduced operation and maintenance costs, and/or higher scrap values, for future challengers.

Technological changes of equipment are classified into continuous technological changes and discontinuous technological changes [10]. The continuous technological changes appear as incremental improvements, possibly in efficiency or performance. In general, these small improvements occur constantly. While the discontinuous technological changes emerge as total re-design of an asset which they consider breakthroughs that happen far in the future by assuming they arrive cyclically. There are four models which are presented with different types of technological change: no technological change, continuous, discontinuous, and both continuous and discontinuous technological change [10].

Technological changes are very significant for industries because most assets undergo both constant improvements and occasional breakthroughs. However, in many industries such as automobiles and computer chips, these breakthroughs are quite predictable; in other industries the breakthroughs are not easily forecasted.

Table 1. Example of continuous and discontinuous technological changes

<i>Changes</i> <i>Asset</i>	Incremental improvements	Breakthroughs
Vehicle	Annually	4-6 years
Computer chip	Quarterly	1-2 years

Table 1 illustrates an example in automobiles and processors for personal computers. In general, in the automobile industry, small improvements, possibly in efficiency or performance may occur annually; while, the total re-design of a vehicle might only occur every 4-6 years. In computer industry, incremental improvements in the chips are made quarterly while breakthroughs occur every 1-2 years.

Based on reviewing existing models of the technological aspect of asset life, the technological life of an asset can be modelled based on the trade off in different costs as shown in Figure 1. Some examples of these costs are: purchase cost of the challenger (new technology), procurement and operating cost of both defender (current technology) and challenger, maintenance cost of defender, salvage value of the defender (current technology), revenue of both defender and challenger in certain period time, other costs of technological change (e.g. loss of goodwill, loss of productivity and competitiveness in market, which new technology still is not accepted), and the probability of appearance of new technology.

2.3 Economic life

The economic life of an asset is the period until economic obsolescence requires replacement with a lower cost alternative. In other words, a piece of equipment is no longer valuable economically, although it still may be usable physically [1, 11]. The economic life of an asset describes the optimal replacement age that minimises acquisition, operating, maintenance, and salvage costs over a (infinite) horizon. As corporate and government entities rely on capital assets for the production of goods or delivery of services, the timely replacement of an asset is imperative to uninterrupted, economical operations. Conventional economic replacement analysis provides asset purchases and sales decisions over a given horizon based on expected acquisition, operating, maintenance, and scrap costs. However, the periodic usage of an asset is uncertain as operational environments are characterised by randomness. In addition, operating, maintenance, and salvage value costs are directly dependent on an asset utilisation. Therefore, fluctuations in an asset usage alter these costs and subsequently, the economic life of an asset.

Based on reviewing existing models of the economic aspect of asset life, economic life of an asset can be modelled based on the trade off in different costs as shown in Figure 1. These costs are: acquisition cost of the asset, operating cost of the asset, maintenance cost of the asset, and salvage value of the asset.

2.4 Social and environmental life

The useful life of an asset may be determined by external factors not related to the physical life of the asset. In these circumstances, the useful life of the asset may be less than the economic life of the asset. The impact of such a situation to legal is significant, particularly in relation to planning for future capital expenditure [14]. Graber [15] states that profitability (by reducing and optimising the life cycle costs products and maintenance processes) and safety (by reducing the risk to people and the environment) could be the significant factors in legal life. Therefore, the social and environmental aspect of asset life is defined as the period until human desire or legal requirement stipulates replacement due to environmental and social conditions as well as the need for an asset.

Government laws and policies are increasingly introducing the principles of sustainable development on the global scale, which in turn affect international trade agreements. In the area of End-of-life (EOL), environmental degradation has become a major concern, and international governments are formulating “producer responsibility” laws to put pressure on businesses to manufacture products and provide services that minimise the eco-burden. However, both environmental and social issues are affected by such sustainable development.

Recently, not only manufacturers but also customers have become aware of the potential environmental and social problems that could arise by neglecting it. By realising this, manufacturers have started to manufacture products that are environmentally and socially friendly (or green products) to obtain advantage in the marketing platform against their competitors while following the legislation and policies regarding environment and society. Therefore, manufacturers will analyse the product life cycle in order to insert the environmental component into their product design to produce a product that has a low production cost and is environmentally friendly [16]. In addition, manufacturers and asset owners consider the process of manufacturing products, and maintain their assets based on environmental and social regulations. Otherwise, by ignoring these regulations, harmful effects will appear throughout the environment and micro society.

Today's high tech society requires thousands of different products, which ultimately result in billions of tons of materials discarded, most of which ends up in landfills. In 1990, US Environmental Protection Agency (EPA) reported that the amount of waste generated by the USA reached a whopping 196 million tons up from 88 million tons in the 1960s [17]. Parlikad and McFarlane [16] states the five options for recapturing value from discarded assets as well as components: (1) repair and reuse; (2) refurbishing; (3) remanufacturing; (4) cannibalisation; (5) recycling. Furthermore, parts and materials that could not be recovered by any of the above five operations will be disposed. Disposal of assets can affect both the environment and macro society.

Depletion of non-renewable resources and environmental impacts as a result of air emissions, discharges of liquid effluents, and generation of large volumes of solid waste are the most significant environmental issues for many industries [18]. Water usage, energy usage, waste produced, and contribution to global warming are also considered to be significant as environmental issues. As a result of both rapid depletion of the raw materials and an increasing amount of different forms of waste (solid waste, air and water pollution, etc), two usually accepted primary objectives have been gaining momentum: (1) creation of environmentally friendly products; and (2) developing techniques for product recovery and waste management.

Life cycle assessment (LCA) spans over the development, manufacturing, use, and disposal stages of a product. LCA is a process for assessing the environmental, occupational health and resource consequences of a product through all phases of its life, i.e. extracting and processing raw materials, production, transportation and distribution, use, remanufacturing, recycling and final disposal [17]. LCA evaluating and quantifies the energy and materials used and wasted and assesses the impact of the product on environment.

Social issues can be considered from a micro (or internal) and macro (or external) perspective, where the former are related to employees and the latter concern society at large. The internal focus involves the health and well being of employee, and human rights aspects in employee sourcing. The external focus involves the impacts of the operational initiative on four different levels of society: local, community, regional and national level.

3 MODELLING RELATIONSHIPS OF DETERMINANTS OF ASSET LIFE

Asset life is a complex function of multiple aspects, which in turn is a complex function of multiple determinants. System dynamics modelling is a potential approach to depict the complex relationships and synergies between these determinants.

System dynamics can model the complexity, nonlinearity, and feedback loop structures that are inherent in any systems [19]. System dynamics is an approach to identify the behaviour of complex systems over time. It deals with internal feedback loops and time delays, which affect the behaviour of the whole systems. An influence diagram is a visual representation of the feedback loops in a system. The influence diagram illustrates variables and their interactions and interrelationships so that arrows could point out the cause (the arrow's origin) and its direct effect (the arrow's point). According to the causal link representations, each arrow is indexed and marked on how they influence variables. A "+" sign means that the two correlated variables are directed in the same way. Conversely, a "-" sign means that a change in a variable's value consequently induces a change in the variable of destination in the opposite direction.

There are two types of cybernetic loop: negative feedback (balancing) loops or positive feedback (reinforcing) loops. A negative feedback loop exhibits goal-seeking behaviour: after a disturbance, the system seeks to return to an equilibrium situation. In a positive feedback loop an initial disturbance leads to further change, suggesting the presence of an unstable equilibrium [20]. Influence diagrams have two important roles in system dynamics methodologies. First, they serve as preliminary sketches of causal hypotheses during the model development and secondly, they can simplify the representation of a model. Minegishi and Thiel [20] recommends models made up of feedback loops built with symbols of level and flow. The "Level" variables describe the state of the systems by a continuous integration of actions resulting from these systems. However, the "Flow" variables express actions.

A preliminary influence diagram of asset life is developed and illustrated in Figure 2. This graphical model shows the interrelationships among the asset life aspects as well as the determinants. It can be seen that some determinants are common among the aspects, and some have logical relationship to each other.

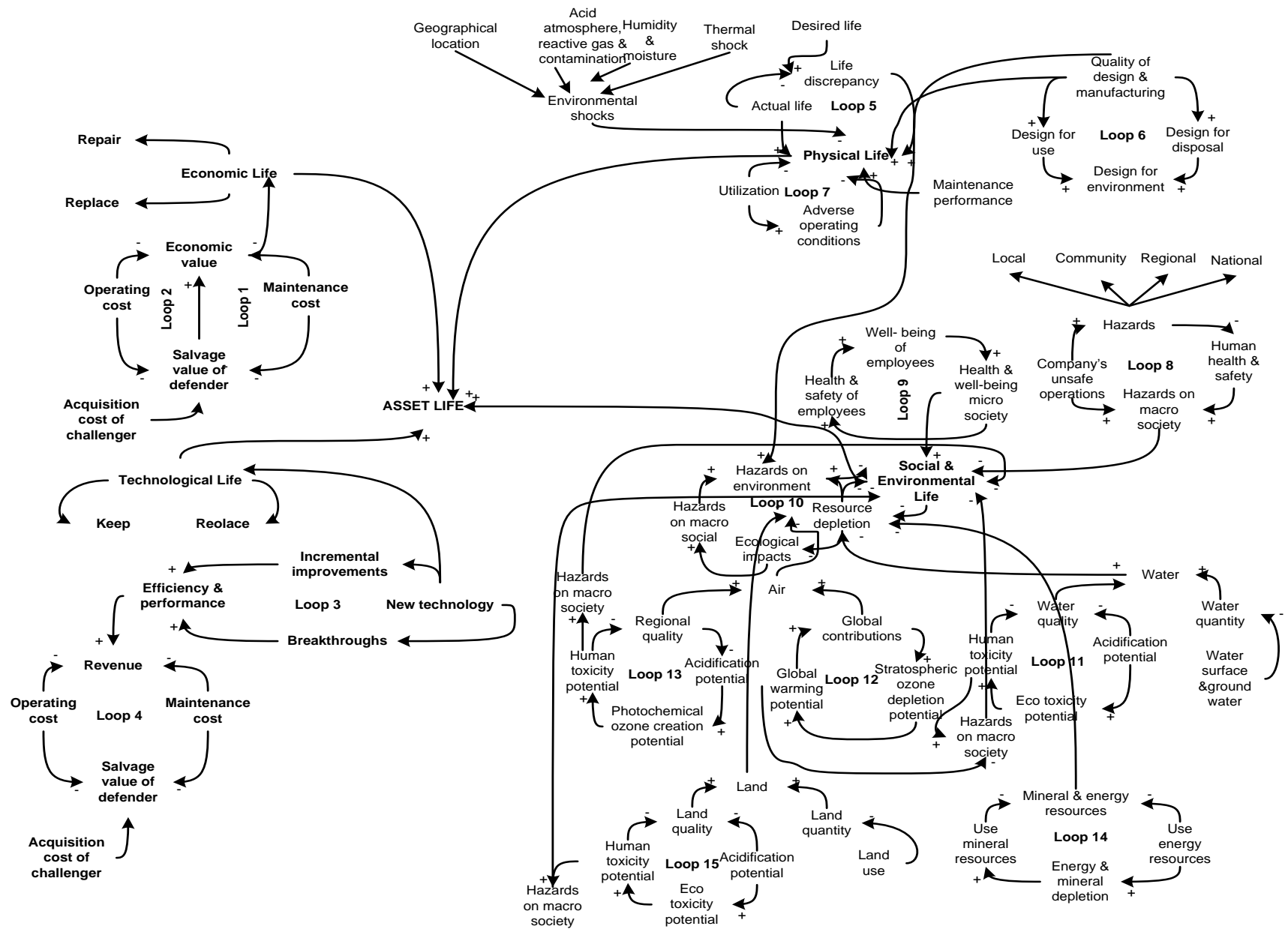


Figure 2. Preliminary influence diagram of asset life

Table 2 briefly illustrates the description of each loop by considering the loop type.

Table 2. Description of the different loops

Loop Number	Loop type	Loop description
1	Reinforcing	Effects of maintenance cost and salvage value on the economic value of the current asset
2	Reinforcing	Effects of operating cost and salvage value on the economic value of the current asset
3	Reinforcing	Performance and efficiency of both continuous and discontinuous technology
4	Reinforcing	Effects of maintenance and operating cost on the revenue generated by the current asset
5	Balancing	Life discrepancy (the discrepancy between the actual life and desired life of an asset)
6	Reinforcing	Effects of design and manufacturing on both physical and environmental aspects
7	Reinforcing	Effects of operating conditions, utilisation and maintenance performance on the physical aspect
8	Balancing	Effects of a company's operations on the macro society (external) and environment
9	Reinforcing	Effects of social issues on the micro society (internal)
10	Balancing	Effects of resource depletion and ecological impacts on environmental and social aspects
11	Reinforcing	Effects of a company's operations and discharges of liquid effluents on water quality and quantity
12	Reinforcing	Effects of a company's operations and emissions on global air quality
13	Reinforcing	Effects of a company's operations and emissions on regional air quality
14	Reinforcing	Effects of the use of mineral and energy resources on environment as the resource depletion
15	Reinforcing	Effects of a company's operations and asset disposal on land quality and quantity

4 CONCLUSIONS

The main purpose of this paper is to identify the four possible aspects of asset life, as well as the determinants of each aspect. Asset life is a complex function of multiple aspects and determinants. A number of models have been developed to predict the life of an asset; however, most of these models focus on one aspect. A model jointly considering different aspects of asset life is highly desired in current practice due to increased risk in multiple aspects. This paper identifies these aspects and determinants in order to have overall and accurate view of asset life. These determinants are extracted and identified by surveying and analysing existing models on the four aspects. There are complex synergies and interrelationships among these determinants. Therefore, to model these relationships and interactions among them, the system dynamics methodology is suggested and a preliminary influence diagram of asset life is developed. This graphical model is the initial attempt to model the relationships of the aspects and determinants. In future, this graphical model will be extended, and also a joint model will be developed to predict the accurate asset life with consideration of all aspects.

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